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Intrinisc Angular and Energy Resolution of Electron-Tracking Detectors

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Auspices Statement

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1 Introduction

The purpose of this study was to estimate the intrinsic physics limitations on the angular and energy resolution of electron-tracking type gamma-ray detectors.

In a Compton interaction, one can completely determine the direction and energy of the incoming gamma ray, without measuring the scattered photon's energy, if one can measure the direction and energy of the scattered electron, and the direction of the scattered photon. Multiple scattering of the Compton electron will quickly destroy the information of the electron's initial direction, so practical devices must be able to resolve the original electron direction, i.e., have tracking resolution mucic h smaller than the typical radiation length in the material.

2 Detectors

The detectors considered are a 1 m^3 solid block of either germanium, or two scintillator materials "glass" or "plastic." The properties for these materials are given in Table 1. We assume that these idealized detectors have perfect position resolution and can exactly resolve the entire electron track produce by the Compton interaction.

3 Simulation and Reconstruction

Using Geant4, we simulate events using a mono-energetic source of photons that hit the detector in its midplane, with momentum exactly perpendicular to the detector plane. Events with two or more interactions in the detector are considered in our analysis.

We do not rely on the intrinsic measure of the deposited electron energy, which is expected to be poor for the the scintillator detectors, but instead use the path length of the electron as the measure of the electron energy.

Table 1: Summary of detector properties. "Plastic" is polystyrene scintillator. "Glass" is a proprietary mixture used by Arno Ledebuhr from Collimated Holes, Inc. It has a LKH-6 glass core and borosilicate glass cladding.

Detector	Radiation length (cm)	Density (g/cm^3)	Effective Z
Germanium	2.30	5.32	32
Glass	4.48	3.27	≈ 31
Plastic	42.55	1.03	≈ 4

The electron path length is proportional to the electron energy, but intrinsic statistical fluctuations in the electron range result in an energy spread of approximately 15%, in the range of energies of interest in this study. As an expediant simplification for the analysis, we determine the reconstructed electron energy by smearing the true electron energy according to a Gaussian with $\sigma = 0.15E$.

We take as the experimental measure of the initial electron direction the line connecting the electron production point and a point at some fixed distance along the electron trajectory.

We measure the electron direction using the first portion of the simulated electron track. The length considered is denoted as the "electron track detection metric", and we currently assume that the measurement error using a given portion of the electron track is small compared to how well the electron track direction measures the initial direction of the electron. If the electron path length is less than the detection metric, the event is considered to be unreconstructable. We further assume that we know head from tail for the measured electron momentum.

Finally, we measure the scattered photon direction using the the true position of the two detected interactions. We assume that given the detector requirements for electron tracking that the measurement error on these points is small compared to the distance traveled by the photon between the first and second interaction points.

We then determine the angular (energy) resolution on the initial photon using distribution of reconstructed photon directions (energies) with the true photon direction (energy). We fit these distributions using a Gaussian, and report the σ of the Gaussian as the resolution. For the angular resolution, we take out the $\sin\theta$ solid angle factor which comes in because we are comparing the opening angle between the true and reconstructed photon directions by weighting events by $1/\sin\theta$ before performing the fit.

4 Results

Figures 1 and 2 show the angular and energy resolutions as a function of photon energy for a 50 μm electron detection metric, while Figures 3 and 4 show the equivalent for a 500 μm electron detection metric.

We find that even for a 50 μm detection metric, electron tracking is impossible for photon energies below 1 MeV except in the scintillator detector.

We find that the angular resolution is quite insensitive to the energy resolution assumed.

5 Things to fix

- Add Efficiency plots
- Do angular resolution fits with Gaussian times sin theta function
- Fig 4, why rollover at ¡2 MeV for 500 micon metric?
- All figures change scint to plastic
- All figures change resolution to metric
- Fig 5-8 remove E=1.0MeV

Figures 5 through 8 show the angular and energy resolution for 1 MeV and 2.7 MeV initial photon energies as a function of the electron track detection metric.

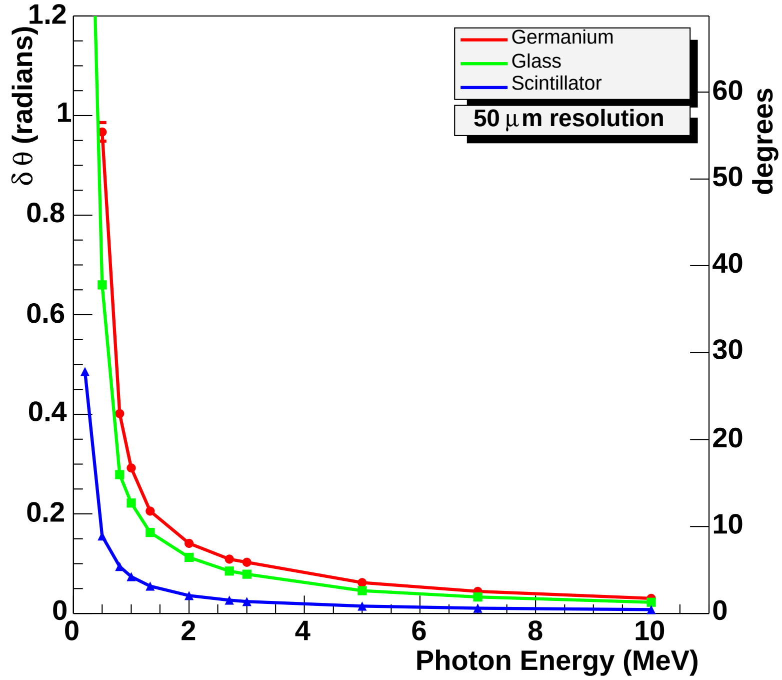

Figure 1: Angular resolution of incoming photon vs. photon energy for a 50 μm electron track detection metric for germanium, glass, and scintillator detectors.

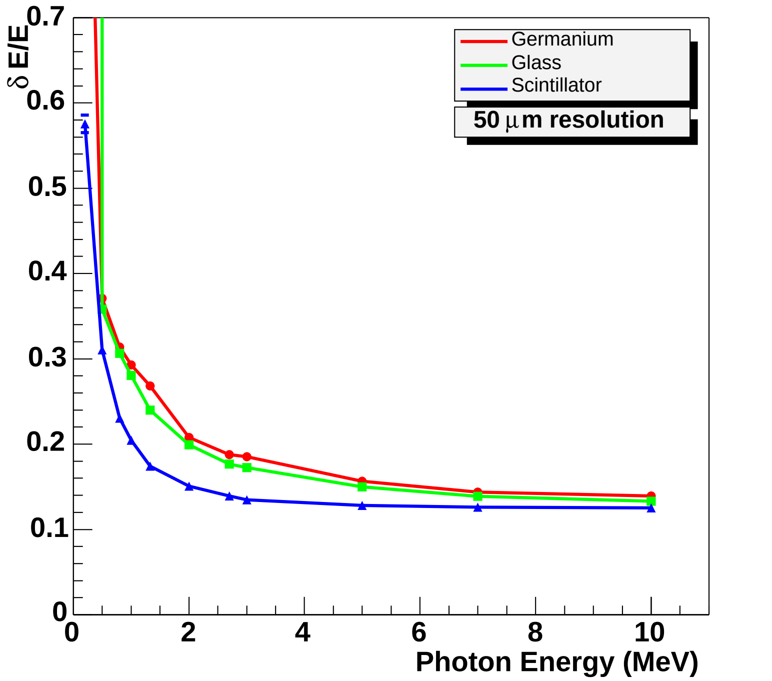

Figure 2: Energy resolution of incoming photon vs. photon energy for a 50 μm electron track detection metric for germanium, glass, and scintillator detectors.

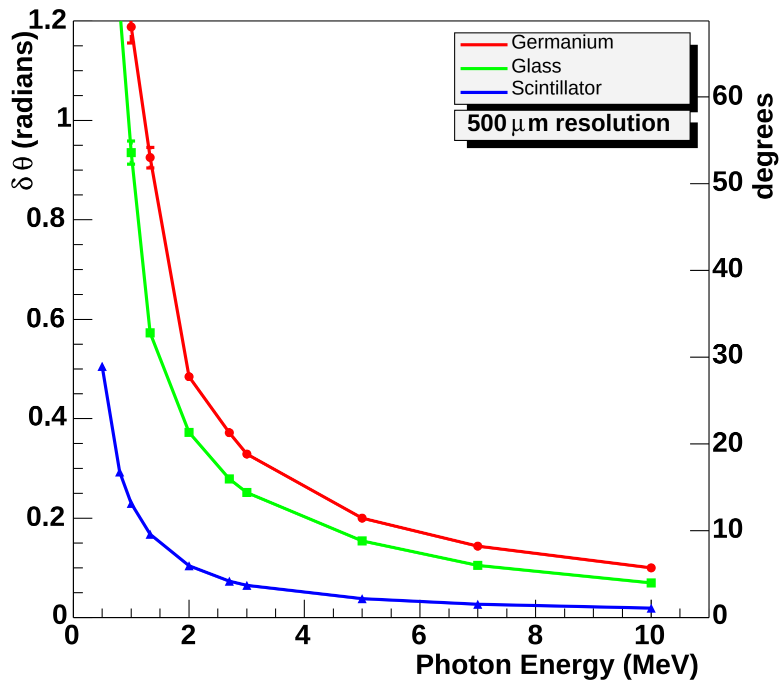

Figure 3: Angular resolution of incoming photon vs. photon energy for a 500 μm electron track detection metric for germanium, glass, and scintillator detectors.

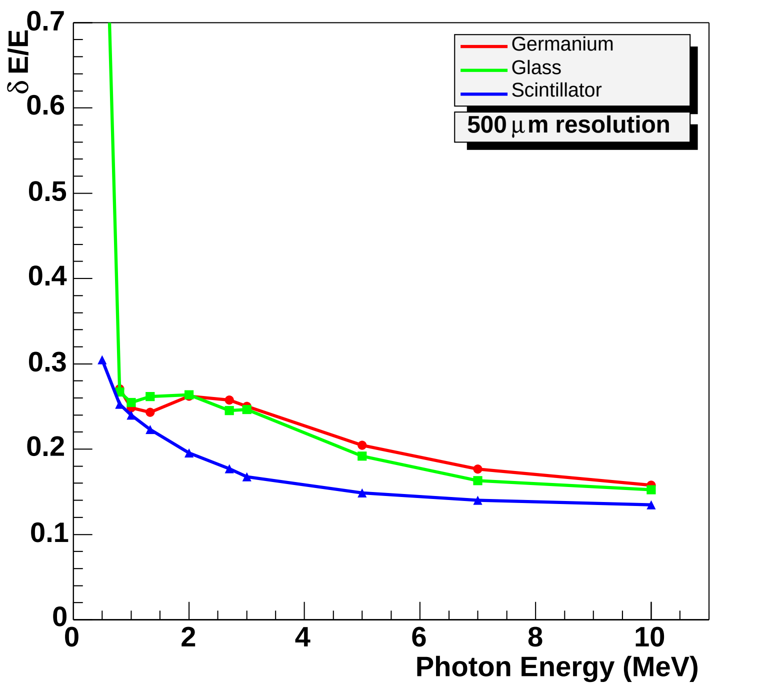

Figure 4: Energy resolution of incoming photon vs. photon energy for a 500 μm electron track detection metric for germanium, glass, and scintillator detectors.

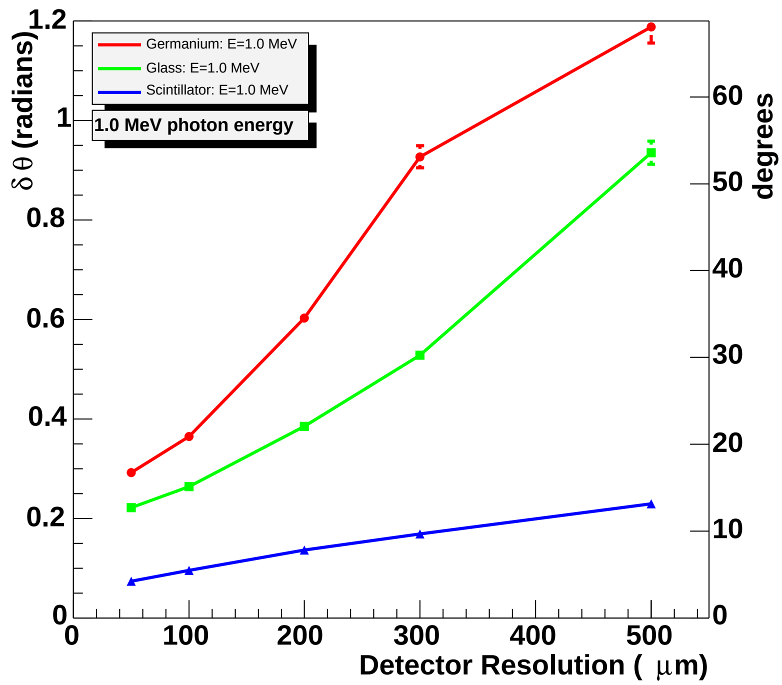

Figure 5: Reconstructed photon angular resolution vs. electron track detection metric for a 1.0 MeV electron track detection metric for germanium, glass, and scintillator detectors.

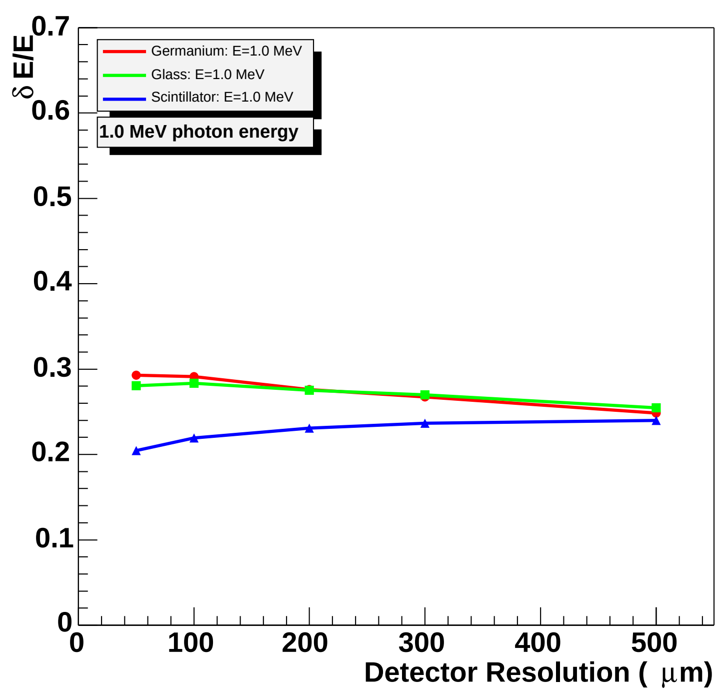

Figure 6: Reconstructed photon energy resolution vs. electron track detection metric for a 1.0 MeV electron track detection metric for germanium, glass, and scintillator detectors.

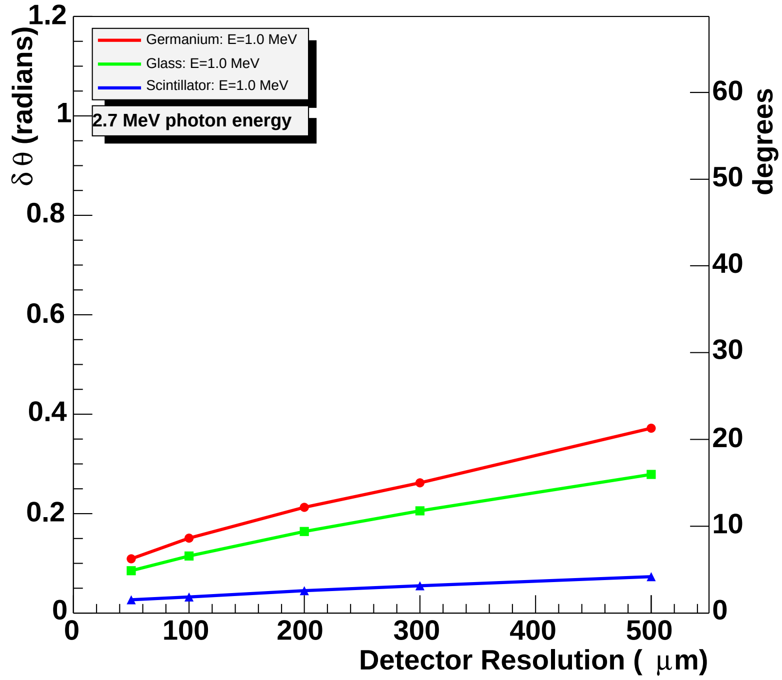

Figure 7: Reconstructed photon angular resolution vs. electron track detection metric for a 2.7 MeV electron track detection metric for germanium, glass, and scintillator detectors.

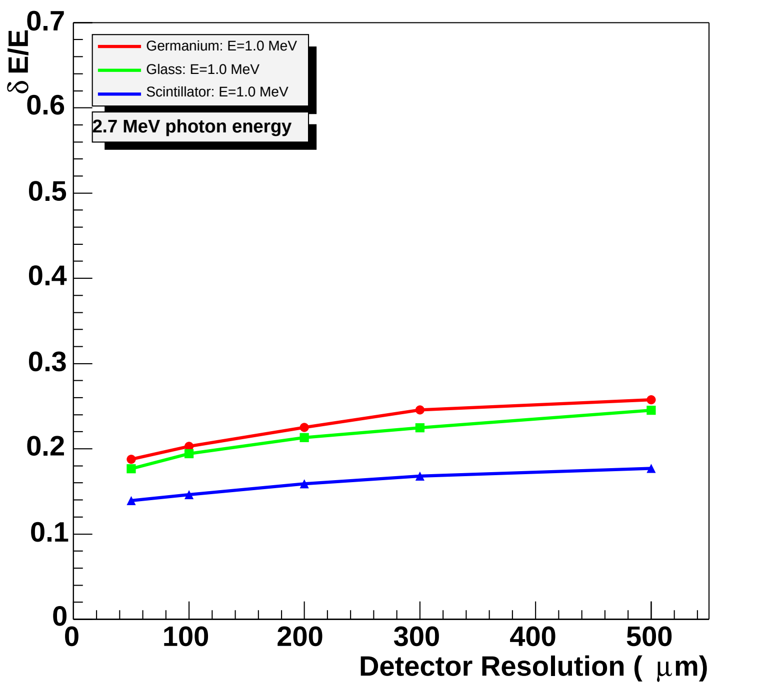

Figure 8: Reconstructed photon energy resolution vs. electron track detection metric for a 2.7 MeV electron track detection metric for germanium, glass, and scintillator detectors.